IMPROVING PASTURES and GRASSLANDS for the NORTHEASTERN STATES

at the U.S. Regional Pasture Research Laboratory

Miscellaneous Publication No. 590

U.S. DEPARTMENT OF AGRICULTURE

FOREWORD

A number of important agricultural problems are primarily regional in scope, as distinguished from others that are limited to individual States and still others that are of countrywide interest. To meet the need for research on such problems, the Bankhead-Jones Act of 1935 provided for regional laboratories, to be administered by the Secretary of Agriculture, which would mobilize scientific resources for a fundamental attack on some of the most important of these problems.

Nine such laboratories have been established. Each deals with a problem or group of problems selected in cooperation with the State agricultural experiment stations of the region as being among the most important faced by agriculture in that section of the country. The States cooperate with the Department in planning and carrying out the research program of each laboratory on a regional basis. At the same time the subjects under investigation are of importance to all major agricultural regions, and the results obtained by the laboratories contribute to agriculture on the national and local as well as the regional level.

This publication is one of a series, each of which describes the work of one of the Bankhead-Jones laboratories, covering the complete program, the results obtained to date, and the continuing research. Papers on various phases of the work have been published by all the laboratories as Department publications and in technical journals.

The laboratories and their locations are as follows:

U. S. Regional Vegetable Breeding Laboratory, Charleston, S. C.
U. S. Regional Pasture Research Laboratory, State College, Pa.
U. S. Regional Soybean Laboratory, Urbana, Ill.
U. S. Regional Swine Breeding Laboratory, Ames, Iowa
U. S. Western Sheep Breeding Laboratory, Dubois, Idaho
U. S. Regional Animal Disease Research Laboratory, Auburn, Ala.
U. S. Regional Poultry Research Laboratory, East Lansing, Mich.
U. S. Regional Salinity Laboratory, Riverside, Calif.
U. S. Plant, Soil, and Nutrition Laboratory, Ithaca, N. Y.

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at the

United States Regional Pasture Research Laboratory[1]

The climate and soils of the Northeastern States, as well as their economic conditions, are well suited to a grassland agriculture. Dairying, which depends on good pastures, is the source of more than a third of the cash income of the farms in the Northeast. This section produces over 2 billion gallons of milk a year. More milk and milk products are needed, however, to provide an adequate level of nutrition for the people of the region. To increase production of these foods in the Northeast will require more and better dairy cows, and to maintain these animals larger supplies of home-grown feed, particularly pasturage, will be needed.

Productive pastures and other grasslands, therefore, are important to prosperity and health in the northeastern region. In recognition of this fact, the directors of the agricultural experiment stations of the 12 Northeastern States, meeting in New York September 12 and 13, 1935, selected "an intensive and fundamental study of pasture improvement" as the subject of research for a

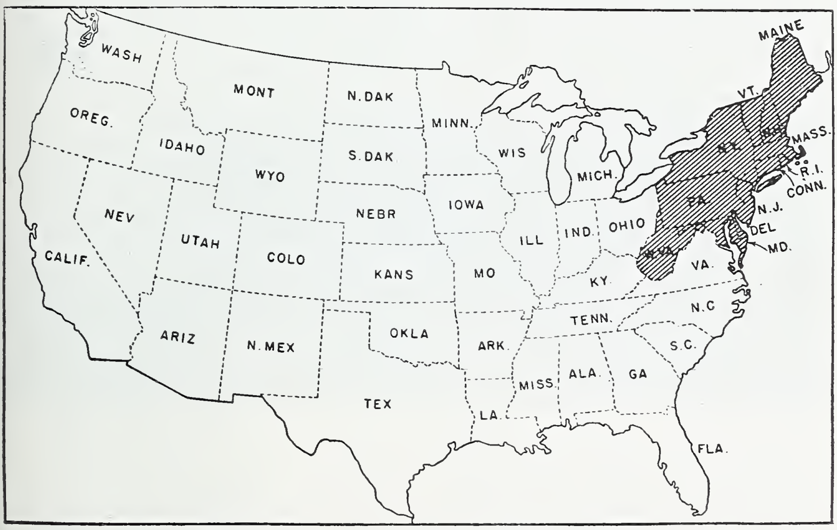

FIGURE 1.—The States cooperating in the work of the Regional Pasture Research Laboratory are shaded.

[1] This publication was prepared under the direction of S. B. Fracker, coordinator of research, Agricultural Research Administration, with the cooperation of the staff of the Regional Pasture Research Laboratory—R. J. Garber, Director, W. M. Myers, V. G. Sprague, J. T. Sullivan, R. R. Robinson, and K. W. Kreitlow.

regional laboratory to be established under the Bankhead-Jones Act. The United States Regional Pasture Research Laboratory was accordingly established at State College, Pa., in 1936. The 12 cooperating States, as shown in figure 1, are Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, and West Virginia.

PASTURE PROBLEMS AND THE LABORATORY'S RESEARCH PROGRAM

Rainfall in the Northeast is usually adequate, especially in the spring, for the growth of pasture grasses and legumes, and the moderate temperatures are also favorable. The fairly high rainfall, however, with the steep slopes found in many parts of the region, has resulted in serious erosion. These losses, together with those from leaching and crop removal, have seriously depleted the productive capacity of the agricultural land. Slopes too steep for cultivated crops may, with proper care, be used for pastures, and the more level soils of the river valleys and coastal plains (fig. 2) can be improved for other crops by rotations that include grasses and legumes.

FIGURE 2.—A typical pasture scene in a more level section of the northeastern region.

The spring weather in the region is favorable to rapid growth of grasses and a relatively high early-season production of pasture or hay. In the summer months, however, the growth of many grasses and legumes declines very sharply and the mature herbage is less palatable and nutritious than new growth, so that dairy cows often do not eat enough in summer to maintain a high milk production.

Lime and mineral fertilizers have increased total forage production, but they have done relatively little to bring about more uniform production throughout the growing season. On badly depleted pastures, it was often several years after fertilizer application before the Kentucky bluegrass and white clover

stand improved enough to increase returns from the pasture. In some instances, particularly on the poorer and drier sites, returns from liming and fertilization did not repay the cost.

This was the earlier status of the pasture problem throughout most of the northeastern region. In recent years the concept of pastures has undergone some marked changes. The distinction between pastures and meadows is less sharp, and the production of forage, including hay, grass silage, and pasture, is now considered as a unit. Permanent bluegrass–white clover pastures will undoubtedly continue to play an important role, but to meet all forage needs of the northeastern region it will be necessary to develop superior varieties, not only of these species but of others, and to work out better management practices. Kentucky bluegrass and white clover are not as well adapted for hay or silage as are some of the larger species now receiving consideration.

The pasture problems of the region that require attention in the research program may therefore be summarized as follows: (1) Increasing production of home-grown feed, particularly pasture, so that greater quantities of milk and other animal products may be produced more economically; (2) providing an adequate supply of nutritious and palatable pasture throughout the entire grazing season, so that milk flow will not decline and relatively expensive supplementary feeding with hay or silage during the summer will not be necessary; (3) stabilization of the forage program from year to year by maintaining well-balanced combinations of grasses and legumes and guarding against the loss of production due to improper grazing, depletion of fertility, drought, excessive soil moisture, and winter-killing; and (4) improvement and conservation of soil resources of the region through a system of grassland agriculture.

For the solution of these problems, superior varieties of the important species of pasture plants, better methods of grazing management, and improved fertilizer practices are needed, and ways must be worked out by which these improved varieties and methods can be utilized by the animal husbandman.

The pasture-forage problem is too complex and extensive for solution by any one State experiment station. The problem is truly regional and requires for its solution the coordinated and cooperative efforts of all research agencies, State and Federal, in the region. The Pasture Laboratory is playing an essential role in this work.

THE LABORATORY STAFF, BUILDINGS, AND EQUIPMENT

The Pasture Research Laboratory is under the administrative direction of the Division of Forage Crops and Diseases of the Bureau of Plant Industry, Soils, and Agricultural Engineering. The laboratory itself, as well as the coordination of such cooperative pasture work as is carried out with the 12 experiment stations, is under the immediate charge of an agronomist as director. The staff includes a geneticist, a biochemist, a plant physiologist, a plant pathologist, a soil specialist, and a number of assistants.

To facilitate the planning, coordination, and integration of fundamental research at the Pasture Laboratory and the agricultural experiment stations, a group of collaborators was appointed in 1936, one staff member being assigned from each of the 12 stations. The collaborators represent most of the fields of research allied to the pasture problems in the region—agronomy, dairy husbandry, plant breeding, plant pathology, plant physiology, and plant chemistry.

The offices of the laboratory are in a fireproof two-story-and-basement

building, adjacent to which are three greenhouses having a total of about 11,000 square feet of floor space. The greenhouses are connected by a brick headhouse which contains a garage, transplanting benches, repair shop, threshing room, and laboratory space.

Five laboratories are equipped for research in chemistry, plant pathology, plant physiology, cytogenetics, and plant breeding. In addition there are rooms for special purposes, including a drying room where forage samples may be reduced rapidly to a uniform low moisture content and seed samples may be processed prior to storage; a weighing and grinding room in which weights of forage samples are determined and in which samples may be prepared for chemical analyses; two low-temperature storage rooms with a combined capacity of about 15,000 cubic feet, in which temperatures as low as 0° to 2° C. (32° to 35.6° F.) may be maintained; and a freezing chamber in which temperatures as low as minus 20° C. (minus 4° F.) may be reached.

Control Chambers Can Reproduce Any Kind of Climate

The results of field and greenhouse experiments on the effects of any factor of the environment on the growth of plants, such as light intensity, length of day, soil temperature, air temperature, soil moisture, relative humidity, or wind velocity, under natural conditions are usually complicated by the variations in each of the factors, so that it is often impossible to separate the effects of one factor from those of the others. To facilitate studies of this kind, climatic control chambers were constructed (fig. 3). These chambers are so designed that air temperature, soil temperature, relative humidity, and length of day are controlled independently by means of time-cycle controllers (fig. 4), and the effects of almost any combination of environmental factors may thus be studied. These controllers can be set to produce not only a desired condition

FIGURE 3.—Front view of the climatic control chambers. The upper doors give access to the plants, which grow in pots set in ethylene glycol brine. There are four chambers, in each of which different environmental conditions can be maintained.

continuously but also a sequence of weather conditions from hour to hour and day to day, according to the requirements of the study being conducted. Four chambers are available, each controlled separately, permitting the simultaneous study of four different sets of environmental conditions.

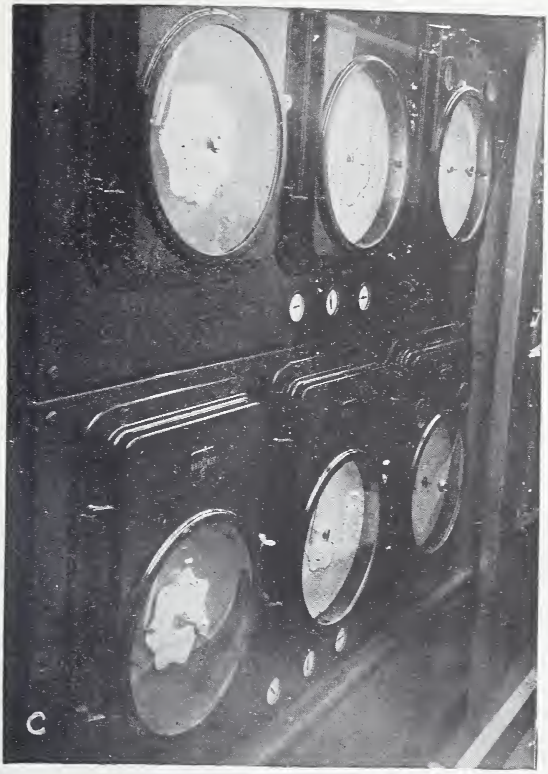

FIGURE 4.—Instruments controlling air temperature, air humidity, and soil temperature in the environmental chambers. By varying the shape of the scalloped disks at the left, any desired combination of these factors can be obtained.

The inside dimensions of each of the chambers are about 5 by 5 feet by 7 feet high. In the lower part of each chamber is a tank of ethylene glycol brine, the temperature of which is automatically controlled. Glazed pots containing the growing plants are set in this brine, which covers the lower part of the pots and maintains the desired soil temperature. The source of light is a bank of twenty-two 40-watt fluorescent lamps with polished aluminum reflectors, arranged just above the glass top of each chamber. The chamber is insulated from the heat of the lights by two sheets of plate glass separated by a 1½-inch air space. Dehumidification, cooling, and heating of the air in the chamber are accomplished by circulating it over coils supplied with either cold or hot ethylene glycol brine as the occasion demands. The humidity may be increased by adding steam to the air stream. The circulation of air over the plants growing in the chambers is normally maintained at the rate of 1 to 2 miles per hour, but this can be increased to gale velocity if desired.

Up to this time these chambers have been used to study such problems as the effect of air and soil temperature on seedling establishment, the effect of

temperature on restorage of food reserves in plants following clipping, the effect of length of light and dark periods on heading, and the effect of temperature on disease as it affects seedling mortality and the value of seed disinfectants.

ESTABLISHMENT, FERTILIZATION, AND MANAGEMENT OF PASTURES

Clover-Bluegrass Mixtures Require Careful Fertilization and Management

The ideal system of pasture management in the northeastern region would result in the maintenance of approximately equal proportions of Kentucky bluegrass and white clover. In order more nearly to approach this ideal it is necessary to know more than we do now about the interrelated effects of liming, mineral fertilization, nitrogen fertilization, grazing management, soil moisture, and various climatic factors, particularly high soil and air temperatures.

The amount of white clover in a Kentucky bluegrass pasture depends on the ability of the clover to compete with the grass. The first consideration in maintaining white clover is the use of adequate amounts of phosphate, potash, and lime. The clover, being a legume, is able to obtain nitrogen by fixation through bacteria on its roots and thus helps supply the nitrogen requirements of the grass. Top-dressing permanent pastures with lime, phosphate, and potash usually greatly increases forage production, but the initial increase in clover may be reversed when the nitrogen produced by the clover stimulates the growth of the grass to such an extent that the clover is crowded out. Nitrogen fertilizers have not been widely used on pastures, partly because of the expense, but also because they, too, stimulate a vigorous growth of grass which tends to crowd out the clover.

The Pasture Laboratory is now engaged in both greenhouse and field studies to determine why white clover persists in association with Kentucky bluegrass in some instances but will not do so in others. Experiments are also in progress to determine the feasibility of supplementing the nitrogen supplied by clover with nitrogen fertilizer without materially decreasing the amount of white clover in the pasture. Trials under controlled conditions in the greenhouse show that with adequate nitrogen fertilizer young grass plants respond better to phosphate fertilization than young clover plants. However, the response of a species when growing by itself may be quite different from its response when growing in association with other species. This is particularly true in the case of grass-clover associations.

Grazing management, as well as fertilization and liming, greatly affects the proportion of clover. Heavy nitrogen fertilization and light grazing or infrequent clipping usually result in a pasture with little or no clover. Nitrogen fertilization may be desirable, however, especially when, because of drought or disease, the clover has been largely eliminated. Even when clover is present, nitrogen may be used to increase production early in the spring.

Studies at the Pasture Laboratory and at some of the State agricultural experiment stations have shown that the tendency of nitrogen fertilizer, applied in the spring, to stimulate the grass so that it crowds out the clover can be counteracted by grazing the grass closely until the clover has an opportunity to start growth. This system of fertilization and management gives high yields in the spring but is less favorable to the grass during the hot summer, when clover seems better able to compete with grass provided adequate moisture is available. This is explained in part by experiments in the temperature-control

chambers, in which it was found that the optimum temperature for the growth of clover is higher than the optimum for Kentucky bluegrass.

Adequate soil moisture is also a very important factor in producing increased yields of herbage and in maintaining a desirable stand of white clover. Both Kentucky bluegrass and white clover are relatively shallow-rooted and are usually unproductive during July and August. White clover in association with Kentucky bluegrass is particularly susceptible to injury from drought and during prolonged dry periods may be completely killed, especially on the drier soils.

Field experiments on irrigated plots have shown that both white clover and Kentucky bluegrass will make excellent growth during July and August if supplied with adequate moisture and, of course, with fertilizer and lime. The high percentage of clover on the irrigated plots also suggests that irrigation may indirectly be a factor in supplying the nitrogen needs of the pasture. This possibility needs further investigation, and further studies are also required to determine whether the increased production will ever be great enough to justify the expense of irrigation.

Run-Down Pastures Can Be Renovated with Larger Grasses and Legumes

It has become apparent that in spite of the increased production obtained from top-dressing permanent Kentucky bluegrass–white clover pastures with lime and fertilizers, this treatment does not provide the solution to the pasture problem. Midsummer production cannot be increased sufficiently by this means to afford a uniform supply of pasture throughout the grazing season. In the more seriously depleted permanent pastures, in which poverty grass and broomsedge are the predominant vegetation, the increase in Kentucky bluegrass and white clover after fertilization has been relatively slow, thus delaying returns.

To help solve this problem, the pasture specialists of the laboratory and cooperating experiment stations have turned to the larger grasses and legumes. Of these, orchard grass, bromegrass, Ladino clover, and alfalfa seem at present to be most promising for the region as a whole. The old standard hay mixture, timothy and red clover, though useful under many conditions, is not productive during midsummer, nor is the red clover sufficiently long-lived for satisfactory rotations in a grassland agriculture. Other species that may prove valuable include reed canary grass, tall oat grass, tall fescue, and birdsfoot trefoil. These larger, deeper rooted species are better able to continue growth during dry periods of midsummer, and they also provide a greater total amount of herbage. Furthermore, they are suitable for three different uses—hay, grass silage, and pasture. Thus, during the most productive period of permanent pastures, the excess spring production of the large grasses and legumes may be harvested for hay or for grass silage, leaving the field available to provide additional pasture during the normal period of low production.

At first the larger grasses and legumes were used only on the plowable cropland as part of the regular rotation. Cropland is not plentiful, however, in the northeastern region and ordinarily is not used for a grass crop in the rotation longer than necessary for good soil management. Recently, however, it has been discovered that these larger grasses and legumes can be established in old pasture areas by "renovation."

Many of the States in the region are engaged in experimental work on problems related to the renovation of permanent pastures. In order to coordinate these studies and to assist in furthering work on some of the basic

problems involved, cooperative experiments are being conducted with the Connecticut, Maine, Massachusetts, Pennsylvania, Rhode Island, and Vermont Agricultural Experiment Stations and with the Division of Forage Crops and Diseases at Beltsville, Md.

Bog Harrow is Useful for Preparing the Seedbed

One of the primary problems in renovation has been to determine methods of establishing stands of the larger grasses and legumes in unproductive pastures, particularly where plowing is impossible or undesirable. Results have been variable, depending on the pasture, the soil type, the weather, the species used, time of seeding, seedbed preparation, and other factors. In order to obtain more information on the interrelationships of these factors, the Pasture Laboratory has devoted considerable time to problems related to seedling establishment.

Work in cooperation with several State stations has been directed toward methods of seedbed preparation. A primary prerequisite of an adequately prepared seedbed is the killing of the existing vegetation. The results of experiments at State College indicate that for satisfactory elimination of the existing sod or weeds the plow is probably the best implement on land where erosion does not threaten. It has been as economical from the standpoint of labor and power as any other implement. However, since the old sod is all turned under by the plow, the resulting seedbed is unprotected and subject to erosion, baking, and crusting.

The implement which appears to be most satisfactory for use on erodible land is the heavy cutaway disk (bush and bog harrow) (fig. 5). Preparation

Figure 5.—Working up pasture sod with a heavy cutaway disk (bush and bog harrow). This implement kills existing vegetation without plowing and can be used to mix lime and fertilizer into the surface soil in preparation for seeding on frozen ground the following spring.

of the seedbed with this implement is preferably done in midsummer, since hot, dry weather will kill the sods cut by the disk. In the event of showers, sods may root down again, and several diskings may be required to loosen them. Lime and fertilizer are often applied before the last disking. The resulting seedbed may be somewhat rough, but it is not subject to erosion even on rather steep slopes. It is ideal for surface seeding on frozen ground and is more receptive to moisture than plowed ground. On plowed land the beating effect of rain badly puddles the surface layer of many soils and thus increases run-off, whereas the stubble remaining on disked areas prevents puddling and greatly increases moisture penetration.

The other implements used appear to vary in their adaptability depending on the sod to be worked, the stoniness of the land, etc. Any implement that can be used to kill the existing plants and retain them in the surface layer of soil would appear suitable for use on areas difficult to plow or subject to erosion.

Certain pastures in the Northeast are so rough and stony that the use of a tillage implement is not feasible. To discover if possible a means of renovating such pastures, work is being conducted by the Connecticut (Storrs) Station in cooperation with the Pasture Laboratory on the application of herbicides to eliminate the existing species so that the seeded grasses and legumes can be adequately established. Results of preliminary trials with several of the chemicals used have been encouraging.

Heat is Harmful to Newly Seeded Pastures

The climatic control chambers at the Pasture Laboratory have provided a means of determining the effects of air and soil temperatures on the establishment and growth of varieties of the grasses and legumes under test. It has been found that high temperatures (particularly high soil temperature) retard the emergence and subsequent growth of most of the commonly used perennial forage grasses and legumes. Such species as Ladino clover, Kentucky bluegrass, colonial bentgrass, and timothy were particularly sensitive to hot weather in these trials. Other species, including alfalfa, alsike clover, orchard grass, and bromegrass, were inhibited to a lesser degree.

At lower temperatures there are more roots in proportion to tops, and this may be an important factor in the survival of the seedlings during periods of adverse weather. As a result, summer seedings of some of the sensitive species, such as Ladino clover, have resulted in failure. In line with these findings, most seedings on experimental renovated pastures are now being made on frozen ground in late winter or early spring without a companion crop. Thus, when the temperature becomes sufficiently high, germination takes place and growth is made at temperatures conducive to vigorous root and top development.

Orchard Grass and Ladino Clover Provide a Promising Combination

Throughout much of the Northeast, red clover, alsike clover, and timothy are used as the standard hay mixture. Because of the limited carry-over from this mixture after the first hay year, there is a need for legumes which are longer lived than red and alsike clovers, and for grasses that produce more midsummer growth than timothy (fig. 6). Bromegrass and alfalfa have been an outstanding hay mixture in several Midwestern States and warrant further

FIGURE 6.—A good stand of Ladino clover, orchard grass, and alfalfa, the result of seeding a poor pasture area that had been limed, fertilized, and disked. This is a nearly ideal combination of plants where it can be maintained.

trial in the Northeast. Other species of grasses and legumes such as meadow fescue, reed canary grass, tall oatgrass, and birdsfoot trefoil, which have received less attention but show promise, are being investigated in various associations for use under the varied conditions in the Northeast.

Of the newer mixtures used, orchard grass and Ladino clover are promising, especially when used for early-cut hay or grass silage and late-season pasture. For much of the region, this seems to be the most satisfactory combination available at the present time. Orchard grass has the ability to recover rapidly following grazing or mowing and to continue growth during midsummer when temperatures may be high and rainfall limited. Ladino clover, a relatively new legume in the northeastern region, unlike red clover, is a perennial, and for pasture or hay is more productive than white clover. The mixture requires good fertility, which can be achieved by incorporating adequate amounts of lime and fertilizer into the soil at the time of establishment and by subsequent top-dressings of phosphate and potash.

Maintaining the Proportions of Orchard Grass and Clover

The maintenance of the combination of orchard grass and Ladino clover in a highly productive condition, with a proper balance of grass and clover, is one of the major problems of management. How to secure this desired proportion, and how to maintain it from season to season and year to year are difficult problems that the Pasture Laboratory is now actively engaged in studying.

The climatic control chambers at the Pasture Laboratory have proved invaluable in providing answers to these questions. It has been shown, for example, that the rather wide optimum temperature ranges of orchard grass

and Ladino clover are similar and that both are approximately the same as the range generally found during midsummer over a large part of the region. Thus, except for occasional periods of exceptionally hot weather, temperature is probably not the limiting factor of summer growth in the central and northern part of the northeastern region (fig. 7).

FIGURE 7.—Ladino clover and orchard grass growing in the climatic control chambers. There they make optimum growth within about the same temperature range, a range which coincides closely with that prevailing in midsummer in a large part of the Northeast.

A delicate growth balance exists between two plants with similar temperature optimums. For example, Ladino clover, like white clover, fixes nitrogen, which stimulates the grass and makes it so vigorous that it inhibits the growth of the clover. In order to maintain a balanced growth of the two species, orchard grass must not be seeded too heavily, yet there should be sufficient grass to provide a suitable mixture. Even when great care is taken in seeding, the orchard grass may still crowd out the Ladino clover unless the grazing or cutting practices are controlled.

Work at the Pasture Laboratory on the utilization of carbohydrates stored by the plants as reserve food has led to improved cutting schedules under which the vigor of the grass is maintained at nearly the best stage for the growth of the clover. In a greenhouse experiment, for example, it was found that new growth made by the plant after cutting is produced to a large extent at the expense of stored food, and that not until 10 or 12 days after cutting does the plant begin to restore the food used up in producing the new growth.

It is further evident from this work that the largest proportion of the stored food is not in the roots but in the stubble or lower portions of the leaves, and that the amount increases progressively from the leaf tip back to the soil surface. In another study it was found that at high temperatures there was little or no restorage of food reserves even after 40 days, whereas at progressively lower temperatures down to the optimum restorage began considerably sooner.

Based on such fundamental information as this, field experiments are now being conducted to determine how time, height, and frequency of cutting can be used to maintain the desired proportions of grass and clover and at the same time to produce a maximum yield of nutritious herbage without jeopardizing the longevity of the stand.

Still another factor of this management problem is the use that will be made of the orchard grass–Ladino clover pasture. These large-sized species can be used on the farm for hay or silage in the late spring or early summer, when there is usually sufficient pasture on other areas, and during midsummer the aftermath from the hay or silage can be used for pasture. Trials are now being conducted to determine the effects of managing such pastures for early hay or silage, for late hay or silage, and for all-season grazing. In these studies bromegrass–Ladino clover associations are being used, as well as the orchard grass–Ladino clover. Results so far indicate that, for best survival of the clover, cutting at the prebloom stage of the grass is better than cutting at full bloom, and that, in general, cutting at heights of 3, 2, and 1 inches progressively increased the amount of clover.

It is known that nitrogen fertilizer applied to pasture lands will increase growth in early spring when temperatures are too low for fixation of nitrogen by the legumes. However, the use of nitrogen in orchard grass–Ladino clover associations reduced the amount of clover, not only in the first harvest but also in subsequent growth. It appears that nitrogen does not directly discourage the clover, but its stimulating effect on the grass enables it to crowd out the clover. Measurements of sunlight in a mixed stand of bromegrass and Ladino clover which was allowed to reach the hay stage have shown a hundredfold decrease in light near the soil surface. Under such reduced light intensity it is not possible for the clover to compete.

Alfalfa or Birdsfoot Trefoil May Be Used

Alfalfa in combination with bromegrass or orchard grass has been found better adapted than Ladino clover for use as hay, since alfalfa grows erect and thus is better able to compete for light. For use as pasture, however, alfalfa presents a problem somewhat different from that of Ladino clover. Owing to its habit of growth, more of the leaves and stems of alfalfa than of Ladino clover are removed by grazing. This reduces the capacity of alfalfa to manufacture food for its continued growth and survival. Grazing therefore must be controlled to prevent continuous removal of the leaves and stems, and a sufficient time for recovery must be allowed to permit restorage of plant foods.

Birdsfoot trefoil is another legume that has shown promise in parts of the region. It will grow on drier and less fertile soils than alfalfa or Ladino clover and will survive under less exacting conditions of management. However, it has limitations which have not yet been overcome. Perhaps its main weakness is its inability to compete with other species during the seedling stage, which results in a slow rate of establishment. Usually 2 or 3 years are required before it becomes productive.

Unsolved Management Problems

While considerable progress has been made in providing a supply of nutritious pasture herbage throughout the season, many problems remain unsolved. One such problem, in the solution of which only limited success has so far been achieved, is that of maintaining high-producing, intensively managed pastures over periods of more than 3 or 4 years. While this is often long enough for pastures on plowable land used in the regular farm rotation, it would usually be desirable to maintain the renovated pastures in a productive condition as long as possible rather than risk the hazards and incur the expense of reestablishment. Undoubtedly part of the reduction in productivity as the sward becomes older is due to a decrease in the availability of certain fertilizer elements. It also appears that the ingress of Kentucky bluegrass may be a factor. For the solution of these and other problems, fundamental information on the relationships of light, temperature, moisture, frequency of defoliation, height of cutting, etc., is essential. Such information is being sought in many of the experiments now being conducted at the Pasture Laboratory.

CHEMICAL PROBLEMS IN PASTURE RESEARCH

New Analytical Methods Measure Value of Carbohydrates in Forage Plants

Investigations in the chemical composition of pasture plants have in general two objectives. (1) Plants, like all organisms, are made up of chemical substances, and their growth and metabolism are series of chemical reactions. If we can understand these processes we can more intelligently influence the plant in the direction of its greatest usefulness. (2) Forage plants are raised to be consumed by animals, and since their food value to these animals depends on their chemical composition, research aims to make possible the production of the most nutritious forage.

Some compounds, in particular the carbohydrates, provide energy and raw materials for the growth of new plant parts and also furnish calories to the animals that eat the plants. One phase of the chemical studies at the Pasture Laboratory concerns the carbohydrates of the grasses.

An important factor in the studies on carbohydrates has been improvements in methods of analysis. Better methods have been worked out for the analysis of the simple carbohydrates so that the various sugars (glucose, fructose, and sucrose) can be distinguished from one another. The same is true for two of the more complex carbohydrates, fructosan and cellulose. Fructosan has been of special interest. It resembles starch to some extent and performs in grasses the function that starch does in other plants, that of a reserve food which can be used by the plant as a raw material for the formation of such substances as protein, fat, and cellulose and which can also be burned to furnish the energy for these transformations. A method has been worked out for the analysis of fructosan. The Pasture Laboratory is cooperating with the New Hampshire Agricultural Experiment Station in these carbohydrate studies.

The importance of the carbohydrates to practical pasture problems is primarily as reserve or stored substances. Evidence has been obtained that the sugars and fructosan are stored in the lower stalks and roots of the plant. Thus they are not completely removed by grazing and remain to furnish raw material for new growth. Plants with large amounts of stored carbohydrates can make better recovery after severe and frequent grazing than can plants low in stored carbohydrates.

The carbohydrates are also important in relation to their feeding value to animals, one measure of which is their digestibility. Work is planned in cooperation with the Pennsylvania Agricultural Experiment Station to determine the digestibility of the herbage of several forage species. An ultimate objective of this investigation is to develop methods whereby forage may be evaluated by chemical analysis alone without laborious digestibility trials. Another objective will be to discover the comparative feeding value of Kentucky bluegrass, orchard grass, bromegrass, timothy, Ladino clover, and alfalfa.

Analysis for Vitamins, Proteins, and Toxic Substances

Comparisons have been made of strains of the same species of plant that differ only in the number of chromosomes. It has been found that doubling the chromosomes in perennial ryegrass produced small but rather definite changes. The proportions of water and of the simple sugars in the plant increased and that of fibrous substances decreased, which tended to produce a more succulent grass. In white clover, chromosome doubling decreased the fibrous material, but it also slightly decreased the content of carotene, the source of vitamin A.

Studies on leaf rust (*Uromyces trifolii-repentis*) of white clover showed that this disease seriously reduced the carotene, and to a lesser extent the moisture and protein, and increased the fiber, making the forage less nutritious and succulent.

A frequently expressed opinion that dark-green plants are higher in carotene than lighter colored plants was confirmed for orchard grass. This finding should aid in selecting plants with higher vitamin content by color. Improvements were also made in the method for the analysis of carotene.

Several hundred bluegrass plants were analyzed to determine differences in protein content. It was found that the later flowering plants were higher in protein than early flowering plants, even though the difference in the time of flowering was only a few days. The difference in protein content in these plants existed even when flowering did not occur, as at other seasons of the year and in the greenhouse in winter.

White clover sometimes contains hydrocyanic acid (sometimes called prussic acid). This acid, a violent poison, occurs combined in a glucoside, and an enzyme or biological ferment is required to liberate it. In Sudan grass and sorghum it has been known to occur at times in large enough quantities to be dangerously toxic to animals, but it has never been reported to be toxic in clover.

In a study of several thousand white clover plants it was found that about three-fourths contained none of this acid and only a small percentage contained amounts great enough to be suspected of toxicity. To test toxicity a plant found to contain a relatively large quantity, 0.05 percent, was propagated vegetatively to produce enough herbage for a trial. A sheep to which it was fed suffered no ill effects. Why hydrocyanic acid in white clover is nontoxic is not known. The presence in the plant of this acid and of the enzyme concerned has been studied from a genetic standpoint, and improvements have also been made in the method for the analysis of the acid.

Protein Concentrate Prepared from Plants

The wartime shortage of protein-concentrate feedstuffs for livestock—especially poultry and hogs, which are unable to consume large quantities of

fiber—stimulated trials on the preparation of proteins from grasses. It was found that when grass was soaked in alkali and the strained liquid neutralized with acid, a substance was precipitated which when prepared under optimum conditions contained about 40 percent of the protein originally present in the grass and had more than twice the protein concentration of the grass. The best preparations contained over 60 percent protein, more than is found in any available protein concentrates of plant origin. Moreover, they are almost free from fiber. Rapidly growing grass gathered in the spring was especially suitable for the preparation of this concentrate, whereas mature hays were a poor source. The nutritional value of these concentrates will be studied. It is not yet certain whether the need for protein concentrates will remain sufficiently great to justify commercial exploitation.

Steam-Sterilization Injury Can Be Corrected by Phosphates

In growing plants in greenhouses it has long been customary to sterilize the soil with steam in order to control weeds, insects, and disease-producing organisms. Such sterilization is very effective for this purpose, but unfortunately it is sometimes injurious to the crop that follows. The cause of the injury has never been definitely determined. In fact, the nature and extent of the injury varies with the soil, the species of plant, and other factors. In extreme cases injury is so severe that the crop is a complete failure.

Studies at the Pasture Laboratory showed that the injurious effect of steam sterilization can be corrected by heavy phosphate application (fig. 8). Further studies, however, indicated that the injury was not due to fixation of the available phosphate. Basic studies of the chemistry and microbiology of steam-sterilized soils are being continued in an attempt to determine the cause of the injury.

The results of these studies also have an application in the field of vegetable and flower production in greenhouses, as well as in field crops, such as tobacco, that are usually started in steam-sterilized seedbeds.

Figure 8.—The use of phosphate fertilizer helps to overcome the adverse effects of soil sterilization. Pot 1 received no treatment; pots 2 and 3 were sterilized; pot 4 was fertilized but not sterilized; pots 5 and 6 were sterilized and fertilized with phosphate.

BREEDING NEW VARIETIES OF GRASSES AND LEGUMES

Breeding work has been conducted with corn and other cereals, cotton, fruits and vegetables, and other important crops for more than half a century. Even in the case of these crops many unsolved problems remain, but the remarkable achievements stand as concrete evidence of the merits of plant breeding in providing for a prosperous and stable national economy. In contrast, it has been only in the last 15 years that a concerted effort has developed in this country to improve forage crops. Hence, few varieties of forage plants, with the exception of alfalfa and soybeans, are available, and most of these were introduced from plant-breeding stations in Europe, Canada, and elsewhere. Both before and since the introduction of cultivated grasses and legumes into North America, variation has been occurring constantly and the forces of natural selection have been eliminating types unfit for survival under each particular set of conditions.

As a result of these processes, each of the forage crops consists of a heterogeneous mixture of types. In orchard grass, for example, types are found that survive the severe winters of eastern Canada, while others are not winter-hardy even as far south as Maryland. Such extreme variations have been found in orchard grass for each of the important characters desired in a superior variety—size of plant, height, rapidity of recovery following mowing, resistance to important diseases, leafiness, earliness of heading, ability to grow with legumes, ability to withstand lodging, etc. Similar variations have been observed in each of the important grasses and legumes. A study of the range and inheritance of variations within species has formed an important part of the program at the Pasture Laboratory. The search for more and more superior plants representing each of the important characters is being pressed constantly.

These differences among plants are the raw materials of plant breeding. Since plants or strains occurring naturally are seldom outstanding in more than a few of these characteristics, it is the task of the plant breeder to combine the desirable characters from different plants or strains by appropriate genetic and breeding methods, thus synthesizing a new variety superior to each of its parents in one or several ways. The ideal combination of all desirable characters may not, and probably will not, be obtained for many years. The process of building new strains of forage species must proceed step by step, each advance, however, representing a practical benefit in terms of better and more economically produced animal products.

In certain crops—wheat, for example—seed is produced by self-pollination, or fertilization of the egg cells of a plant with sperm from pollen of the same plant. Such plants, subjected in each generation to inbreeding, usually are so constituted genetically that all of the seed from a particular plant will produce plants that are like one another and like the parent from which they came. In such crops, each plant of an unusual type is the potential ancestor of a new variety that would thereafter yield similar progeny. Thus it is necessary only to find or to produce a plant with the desired combination of characters. A similar situation obtains in Kentucky bluegrass, but it is due to the development of the seed by a method in which the sexual process has been eliminated. Thus, most plants of Kentucky bluegrass produce, from unpollinated but fertile seed, offspring that are identical with the parent, just as budded fruit trees within a variety are identical.

Unfortunately the other forage grasses and legumes adapted to the northeastern region are not so simply handled. Each plant normally produces seed fertilized by pollen from other plants, so that the offspring vary widely, none

of them being exactly like the mother plant. In crops that reproduce by cross-pollination, it is not sufficient for the plant breeder to find a plant with the desired combination of characters. Instead, he must devise breeding methods that will permit, under practical conditions, the repeated reproduction of the superior plants.

Certain other problems in breeding forage crops are related to the utilization of the crops in the farm program. Forage plants are desired primarily for their vegetative parts, but in most species superior varieties must also produce enough seed to make their propagation economically feasible. Furthermore, neither grasses nor legumes are commonly grown alone; usually a combination containing at least one grass and one legume is used. Hence, it is necessary that new varieties be adaptable to growing in association or combinations. Finally, an important consideration in breeding new varieties of pasture plants is their reaction to grazing by animals.

Characteristics Sought in New Varieties

High yield, particularly when uniformly distributed throughout the growing season, is one of the prime requirements of a new variety. Evidence already accumulated indicates that, although it will probably be impossible to breed a variety that is as productive during midsummer as in the spring, considerable improvement can be made.

Sustained production of the new varieties from year to year will be an important factor in providing more adequate and more economical feed. For this purpose the varieties must be (1) winter-hardy enough to survive even the most severe winters; (2) resistant to the important diseases that may, when epidemics occur, severely reduce yield and quality of the forage or, as in the case of alfalfa wilt, kill the plants so that the field will be useless until replanted; (3) tolerant to drought and flooding; and (4) able to withstand occasional periods of too little or too much grazing.

Since pastures and meadows should seldom, if ever, be planted to a pure stand of one grass or one legume, varieties of grasses and legumes must be capable of growing satisfactorily in association with one another. This requires that neither grass nor legume be so aggressive that it crowds out the other. The problem of competition of associated species is complicated not only by differences due to variety but also by degree of soil fertility, kind of grazing animals, relative intensity of grazing, and weather conditions.

The forage produced by a new variety must be nutritious. In addition to increasing the amounts of digestible nutrients, vitamins, and minerals in particular varieties, the plant breeder can make real improvement by adjusting the time of maturing. It is well known that variations in nutritive value are greater in the same plant at different periods of growth than between different plants. Hence, a variety that will reach the ideal stage of growth for pasturing or for hay at the proper time is desirable.

A final important quality of new varieties is adaptability to ease of handling. The complexity of the forage program makes it essential that pasture, hay, and grass silage be considered as one problem. Thus pasture may be harvested for hay or grass silage and, conversely, meadows may be pastured. In this machine age, farmers, for maximum economy, must use machinery for harvesting hay and grass silage. The plant breeder must adapt his new varieties to mechanized operations, just as the grain-sorghum breeder has so successfully done in producing varieties adapted for combine harvesting. From

this standpoint, one of the important characteristics in the grasses and legumes is resistance to lodging.

Steps in the Breeding Program

Several steps are followed rather generally in breeding new varieties of grasses and legumes:

Collection of material.—The plant breeder cannot at present create new characters; he is limited to the recombination of desired factors from existing plants. In order to obtain as many superior characters as possible, breeding material is secured from many sources, usually as seed but sometimes as living plants. The Pasture Laboratory has gathered material from the northeastern region and elsewhere in the United States, seed from commercial dealers, superior plants and strains from experiment stations in other regions, and varieties introduced from Europe, Canada, and other parts of the world by the Division of Plant Exploration and Introduction. The value of collections from many sources is shown by the fact that often only one variety among a large number will possess resistance to disease or some other quality sought.

Source nursery.—The collected material is planted in the field with the individual plants spaced far enough apart to maintain their identities. Each plant is produced from a single seed or a single original plant, and the variations among plants from the same and different sources are observed and recorded. The number of plants of each species grown annually in such a nursery may vary from a few hundred to more than 10,000, depending on the amount of new material and the facilities available. Ordinarily a new source nursery of 3,000 to 5,000 plants of each important species is planted each year. In the second year the selected plants are removed and the others discarded. Usually about 5 percent of the more promising plants are saved for further use in the breeding program.

Clonal increases.—The forage grasses and legumes can be reproduced vegetatively by cuttings in a manner similar to the procedure with strawberries and many other fruits. The plants thus produced from an original plant are all alike genetically and constitute what is known as a clone. The selected plants may be increased in this way so as to have available for further steps in the breeding program clonal lines descended from the original selection.

Further tests of selected plants.—To overcome the inaccuracy inherent in the evaluation of a single plant, which may reflect environmental factors in its growth, and to reduce the selected plants to a few especially desirable individuals, further tests of the original selections are conducted. First, numerous representatives of the clones produced by vegetative propagation of the selected plants are grown in a "replicated planting" in rows or as single plants at several widely separated places in the field. This enables the plant breeder to evaluate to some extent the effects of disease and environmental factors and, hence, to select more accurately the superior clones.

The second step is the "polycross" test. Seed from each of the clones which appear promising in the replicated planting is used for broadcast planting of field plots. The plots of the seed progeny of each clone are replicated 4 to 6 times, the entire area is seeded uniformly with a companion species—for example, Ladino clover or alfalfa with orchard grass or bromegrass, or Kentucky bluegrass with white clover—and the plots are grazed or are clipped to simulate grazing conditions. The relative merits of the clones are then deter-

mined from yield, persistence, growth with the companion species (fig. 9), recovery following clipping or grazing, and other characters.

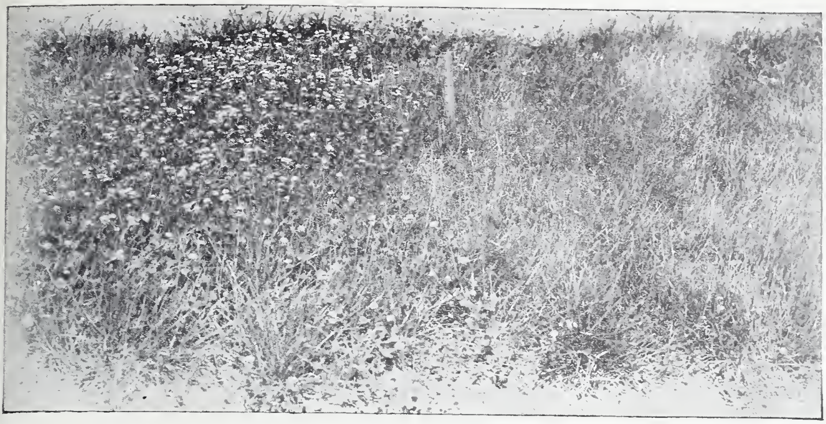

FIGURE 9.—The clone of white clover tried at the right was unable to compete with the bluegrass with which it was planted, while that at the left was vigorous enough to hold its own.

The few superior clones surviving the polycross test are used for synthesizing new strains.

Synthesis of new strains.—The most rapid method of developing new strains is to plant selected groups of plants in isolated plots where the blossoms will be fertilized only by pollen from other plants in the same group. Ten or twelve plants representing thoroughly tested clones are included in each such group. The resulting seed produces plants that combine the characteristics of the clones making up the group. Because the legumes, such as white and Ladino clover, are fertilized by pollen carried from plant to plant by bees, each group of these plants is isolated under a cage within which a hive of honey bees is confined.

Production of inbred lines.—Inbreeding and selection provide the most expeditious method of producing plants that will transmit any desirable characteristic uniformly to their progeny. The importance of inbreeding as a tool in the improvement of cross-pollinated plants has been demonstrated in several species, particularly corn. The general adaptation of the method in breeding forage grasses and legumes must still be proved, but there are good reasons for believing that it will be valuable, at least in many instances. Inbreeding programs are being conducted at the Pasture Laboratory in orchard grass, white clover, Sudan grass, and meadow fescue and are planned for bromegrass, Ladino clover, and alfalfa. The inbreeding will be continued through a sufficient number of generations to provide the desired uniformity, and the resulting inbred lines will be used in the breeding program in the same manner as the selected clones from the source nursery; that is, they will be subjected to polycross testing and the superior lines will be used in producing new varieties or commercial hybrids.

Hybridization.—To produce clones that possess the desirable characters of both the parent varieties requires hybridization of the two types, inbreeding the hybrid plants for several generations, growing several hundred to several thousand plants in each generation, and carefully selecting those with the

desired qualities. This process takes several years and involves for each species the use of many selected clones and crosses. An extensive hybridization program is in progress with orchard grass, alfalfa, Ladino clover, white clover, and meadow fescue, and it is hoped that superior lines will eventually be obtained.

Evaluating new strains prior to distribution for general use.—New varieties of plants must be tested carefully for several years under the conditions in which they will be used on farms before they can be released and recommended for general use by farmers. The forage plants will be used as hay, grass silage, or pasture—sometimes for two or all three of these purposes.

It is recognized that the most accurate method of evaluating the response of a variety to grazing is to use grazing animals, but this involves too much expense and difficulty to be practicable where large numbers of strains are to be tested. Hence the plant breeders at the Pasture Laboratory have substituted the mowing machine for the cow, attempting by adjusting frequency and height of clipping to simulate the conditions of actual grazing. When the originally large numbers of plants have been reduced to a few distinctly promising varieties, these are then seeded in pastures to be grazed by livestock, usually dairy cows.

Improved Varieties Being Tried at Cooperating Experiment Stations

One of the basic principles of plant breeding is that new varieties are more likely to be superior in the locality in which they are produced; attempts to produce at any location a new variety specifically designed for some other part of the region is likely to result in failure. The plant-breeding program of the Pasture Laboratory is accordingly conducted in close cooperation with State experiment stations in the region. The specific cooperative research projects are as follows:

Improved varieties of Kentucky bluegrass are being studied in cooperation with the Pennsylvania and West Virginia Agricultural Experiment Stations. More than 20,000 spaced plants have been grown in source nurseries, more than 10,000 spaced plants have been grown in progeny tests, and approximately 200 new varieties have been included in preliminary plot tests in association with white clover. Of these, about 30 have been subjected to intensive yield tests, and finally four have been seeded in large plots to be grazed by dairy cows. In experiments conducted so far, 1 of these varieties has proved superior (60 to 90 percent increase in yield) to commercial bluegrass during July and August, although its total yield for the entire growing season has exceeded the yield of commercial bluegrass by only about 15 percent.

New strains of orchard grass are being tested in cooperation with the Maryland Agricultural Experiment Station and the Division of Forage Crops and Diseases, Beltsville, Md. About 15,000 spaced plants of orchard grass have been grown in source nurseries, and more than 60,000 spaced plants have been grown in polycross plots and in inbreeding, hybridization, and genetic studies since the Pasture Laboratory was established. About 65 new synthetic varieties have been produced by planting groups of selected clones in isolated plots. Two of these are entered in the uniform grass nurseries where they have given promising results in some tests. Two others have seemed sufficiently promising in preliminary experiments to warrant more extensive evaluation. Several have already been discarded as unsuitable, and 32 are new combinations that are only now ready for testing in broadcast seedings. Some of these

varieties are 2 to 3 weeks later in maturity than commercial seed and are more winter-hardy than the late-maturing strains that have previously been available.

Varietal improvement in white clover is being carried out in cooperation with the New Jersey Agricultural Experiment Station. Approximately the same numbers of spaced plants of white clover as orchard grass have been grown for various purposes. One new variety has been seeded in broadcast plots for evaluation in comparison with standard varieties, and seed of two other new varieties is being produced for use in plot experiments.

Varietal improvement investigations in Ladino clover, timothy, and red clover have been undertaken in cooperation with the New Hampshire Experiment Station. Though these are more recent than studies involving Kentucky bluegrass, orchard grass, and white clover, substantial progress has already been made in the selection of superior and more disease-resistant clones for use in producing new varieties.

In the colonial bentgrass tests, conducted at the Rhode Island Agricultural Experiment Station, several thousand spaced plants have been grown and about 100 selections from them have been tested as clones and polycross progenies. Four groups of clones have been planted in isolated plots to produce seed for new varieties.

Trials of the adaptability of alfalfa varieties to eastern conditions have recently been initiated in cooperation with the New York and New Jersey Agricultural Experiment Stations and the Division of Forage Crops and Diseases, Beltsville, Md.

Fundamental Investigations in Relation to Breeding Grasses and Legumes

The results of extensive studies carried on throughout the world since the beginning of the twentieth century have provided a vast amount of conclusive evidence that the inherent characteristics—those that are transmitted from generation to generation—of living organisms are determined by submicroscopic entities called genes, carried in or on tiny microscopic bodies in each cell known as chromosomes. Each character may be determined by one to many genes, and the simplicity or complexity of transmission of a character from parent to offspring is determined by the number of genes conditioning the character and by the behavior of the chromosomes in cell division.

Plant breeding involves, fundamentally, the production of varieties by bringing about the proper combination of genes and hence of the characters determined by those genes. It is readily apparent, therefore, that a plant-breeding program can be planned accurately and precisely only when the details are known of the number and action of the principal genes producing each important character of the plant, and of the behavior of the chromosomes that carry those genes from cell to cell of the same plant and from parent to offspring through succeeding generations. With this knowledge, the transmission and recombination of particular characters can be predicted with great precision, thus facilitating the development of the most efficient and effective methods of breeding.

It is for these reasons that a large proportion of the Pasture Laboratory breeding program has been and will be devoted to studies of the inheritance of important characters—self- and cross-sterility, self- and cross-fertility, disease resistance, earliness, winter hardiness, chemical composition, vigor, etc.—and the behavior of the chromosomes during cell division, particularly at the time of the production of sperms and eggs.

Using powerful microscopes (some give magnifications as great as 2,700

times natural size, though most frequently magnifications of about 900 times are used), the regularity of chromosome movement during cell division has been studied in orchard grass, perennial ryegrass, meadow fescue, timothy, and white clover. It has been found that certain differences in the chromosome behavior are reflected in different types of transmission of characters from parents to progeny and in differences in fertility of the plants.

Although most plants of any particular species have the same number of chromosomes (14 in meadow fescue, 42 in tall fescue, 28 in orchard grass, 42 in timothy, 32 in white clover, Ladino clover, and alfalfa), some plants have been found with more or fewer than the usual number. In many cases the deviation in number of chromosomes adversely affects the vigor, appearance, and fertility of the plant. In orchard grass, the production of such inferior plants results from certain abnormalities of chromosome behavior that can be observed with the microscope.

During two of the cell divisions, known as meiosis, preceding the development of sperms and eggs, the chromosomes come together in pairs in most plants and animals. In such plants and animals, characters determined by a single gene segregate in a simple 3:1 ratio. For example, if a plant with yellow leaves is crossed with a plant with normal green leaves, all of the hybrids are normal green. When the hybrid plants are self-pollinated or crossed among themselves, three-fourths of the resulting plants will be normal green and one-fourth will be yellow. In orchard grass, it was observed by microscopic examination that the chromosomes came together in groups of four instead of in pairs. From a knowledge of chromosome behavior, it was postulated that in orchard grass only 1 plant out of 36, on an average, would have yellow leaves, and results of genetic studies confirmed this expectation. Similar results were obtained with timothy.

Several methods have been developed for producing plants with twice the normal number of chromosomes. Of these methods, one using the old gout remedy, colchicine, has been found most effective at the Pasture Laboratory in producing such forms in perennial ryegrass, meadow fescue, white clover, red clover, and alsike clover. Plants with the double chromosome number differ in morphology, physiological reactions, and chemical composition from the normal type. As yet, none have been obtained that are superior to normal plants. The material has been particularly valuable, however, in the solution of several fundamental problems which could not have been studied with the normal material. The type of chromosome behavior and inheritance in orchard grass has led to the theory that it arose in nature by doubling of the chromosome number in a related species found wild in Europe. Recently, by the use of colchicine, the chromosome number of plants of the wild species has been doubled. This should provide material for the analysis of many problems in orchard grass.

Although the intensive investigations of fundamental problems of heredity in forage grasses and legumes have already yielded information of great value in planning and executing the breeding program, a great number of unsolved problems still remain. It is only on the firm foundations of fundamental knowledge that the structure of a plant-breeding program can be built. The results of such investigations are applicable to plant breeding throughout the region, the nation, and the world.

PLANT DISEASE PROBLEMS OF GRASSLANDS

An important phase of work at the Pasture Laboratory is the study of the diseases that attack pasture plants and determination of methods of control.

No matter how desirable a clone of grass or clover may be, it cannot be utilized to best advantage in a grassland system of agriculture if it is susceptible to diseases which may be prevalent in the region.

Since the region served by the Pasture Laboratory presents a considerable range in soil and climatic conditions, different strains of an organism or even different organisms may parasitize a given host in different parts of the region. Consequently, an important part of the pathological research consists of examining different pasture species in widely separated parts of the region and determining the pathogens attacking these species. This effort has revealed some diseases not previously observed on pasture plants in some of the States in the region and insures an early diagnosis and direction of effort to combat those diseases that might become destructive in the future.

Disease-Resistant Grasses Sought

One of the first diseases investigated at the Pasture Laboratory in cooperation with the Pennsylvania State College was snow mold of grasses, caused by a fungus (*Typhula* sp.). Since wet, snowy winters are most favorable for development of this disease, the severity of injury depends to a considerable extent on the weather. This means that only one season in several might prove favorable for development of the disease, so that tests of strains of grasses for resistance might have to be confined to such seasons. To eliminate this difficulty a method was developed whereby grass seedlings could be tested for resistance by exposing them to infection for 3 to 5 months in flats of sand maintained in a cold room. This procedure is therefore now used at the laboratory as standard practice for testing new varieties of orchard grass for resistance to snow mold.

A disease now under investigation in cooperation with the West Virginia Agricultural Experiment Station is stripe smut of grasses caused by a fungus, *Ustilago striaeformis*. This disease has been found to be fairly prevalent in Kentucky bluegrass pastures. Of the many pastures examined, only a few were found free of the disease. At the time of examination, smut was found in 1 to 10 percent of the plants in different pastures. A more intensive examination revealed that many healthy-appearing plants harbor latent infections of the organism. When these plants were grown in a greenhouse and examined from time to time, smut lesions eventually appeared in the leaves, and diseased plants were readily identified. As a result of this study, some pastures were found to have as many as 34 percent of the plants infected with the disease. This may help to explain why bluegrass plants in some pastures die out in midsummer, since the weakened, diseased plants appear less able to survive hot, dry weather.

The most promising method for control of smut of Kentucky bluegrass is to breed resistant strains. For this purpose, strains of grasses must be inoculated with spores of the organism. Since most such spores germinate only after they have been stored for 190 or more days, the first problem was to discover a treatment that would provide germinable spores for inoculation purposes in a shorter time. It was found that smut spores could be rendered germinable in 10 to 20 days by exposing them to temperatures of 90° to 95° F. under humid conditions.

In cooperation with workers at the West Virginia station, grasses are being tested for resistance to stripe smut. Since many species of grasses are attacked by races of this smut, cross-inoculation studies are necessary. These will deter-

mine whether or not the races of smut parasitizing Kentucky bluegrass can also attack orchard grass, redtop, or timothy, and vice versa.

To breed an orchard grass resistant to leafspot is a major objective in the Pasture Laboratory's present pathological program. Although many thousands of plants have been examined for possible resistance during the past several years, most have proved more or less susceptible to the causative organism (*Stagonospora subseriata* var. *maculata*). Lesions from new infections appear on the plants throughout the growing season from early spring until late fall. Work at the laboratory has been concerned with studying the life history of the organism and some of the factors that influence development of the disease.

Meadow fescue in the Northeastern States suffers from two destructive leaf diseases, crown rust (*Puccinia coronata*) and net blotch (*Helminthosporium dictyoides*). Among a large number of plants of meadow fescue collected by the laboratory from natural stands, commercial seed, and introduced varieties, those from one lot, from Orono, Maine, proved immune or highly resistant to crown rust. Equally important experiments are being conducted on the net blotch disease. A few collections of meadow fescue have proved highly resistant to *H. dictyoides* in greenhouse inoculation tests. By combining the rust resistance of some plants with the resistance to net blotch of others, it is expected that a variety of meadow fescue can be obtained that will have resistance to both diseases.

Greenhouse tests have shown that different infection types of crown rust and net blotch can be obtained under controlled conditions. Consequently, plants representing different degrees of susceptibility to each disease are being used to study the inheritance of disease resistance in meadow fescue.

Diseases Reduce Yields of Pasture Legumes

Northern alfalfa-growing areas have long been scourged by the bacterial wilt disease (*Corynebacterium insidiosum*). Alfalfa growing is further complicated by the prevalence of destructive leafspot diseases, principally *Pseudopeziza medicaginis*. Although a plant may be resistant to the wilt disease, it is still not desirable if it is largely defoliated because of susceptibility to leafspot. With this in mind, a breeding program has recently been launched to combat these two diseases.

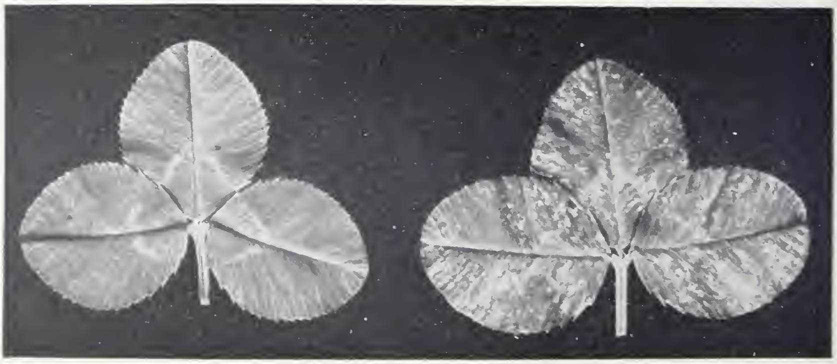

FIGURE 10.—A healthy Ladino clover leaf (left) and one mottled with dead tissue—a symptom suggesting a virus disease.

A disease of Ladino clover undergoing investigation is leafspot (*Cercospora zebrina*). It is known that races of *C. zebrina* occur on other leguminous hosts growing near or intimately associated with Ladino clover. The relationship of the races attacking different hosts is being investigated by cross-inoculation tests and cultural studies of the organism. The results of these tests will help to clarify the problem of breeding a variety of Ladino clover resistant to the disease.

During the course of investigation, plants of Ladino clover that appeared to be infected with an unusual virus disease were examined. As shown in figure 10, the leaves of diseased plants were mottled with spots of dead tissue. In the field, diseased plants were dwarfed (fig. 11) and did not grow as vigorously as neighboring healthy plants. Attempts to transmit the abnormality by mechanical inoculation with juice from diseased plants or by grafts of stolons failed. Furthermore treating diseased parts of a plant in a water bath or incubator at temperatures only slightly lower than the thermal death point of the plant did not stop the spread of the abnormal condition within the plant. Inability to transfer the abnormal condition to healthy plants combined with genetic studies led to the conclusion that the abnormality was heritable. This study illustrates how abnormalities other than those caused by pathogenic agents may appreciably reduce the vigor of plants, just as heritable abnormalities cause similar defects in man or animals.

Studies of Seed Treatment to Reduce Damping-Off

When the seeds of some vegetable and other crops are sown during periods of cool, wet weather they are subject to attack by soil-borne fungi (*Pythium* spp.) that cause damping-off. Many of the seedlings fail to survive and poor stands result. Farmers ordinarily try to compensate for this difficulty by sowing an excess of seed. Tests at the laboratory in cooperation with the Pennsylvania State College indicated that in certain pasture species the problem may be alleviated by treating the seed with fungicides. In 2 years' field tests seedling stands of Sudan grass improved when seeds were treated with Spergon, Arasan, or Semesan (fig. 12).

Extensive field tests with red clover and alfalfa have been conducted during the last 2 years in 18 counties in Pennsylvania. Results to date show that seed treatment with fungicides did not consistently give increased stands.

To determine what factors might influence damping-off and the efficiency of different fungicides, extensive tests have been conducted at the Pasture Laboratory for several years. Among the factors tested have been soil moisture, soil acidity, fertilizer treatments, and soil temperature. The results have shown that each factor contributes to the complexity of the problem and that variation of any one factor sometimes changes the entire picture. Much work remains to be done, but results to date have not demonstrated definite benefits from treating seeds of forage legumes with fungicides.

In experiments to determine the effect of the various fungicides on viability of seed during storage it has been found that New Improved Ceresan, Semesan, Arasan, Spergon, and Yellow Cuprocide had no injurious effects on germination of seeds of red clover, alfalfa, and Ladino clover even when stored for more than a year. On the other hand, Sudan grass seed treated with New Improved Ceresan failed to germinate after 3 months' storage under the most favorable conditions. It seems probable that certain legume seeds could be treated with fungicides to eliminate surface seed-borne organisms and could then be stored as long as a year before planting.

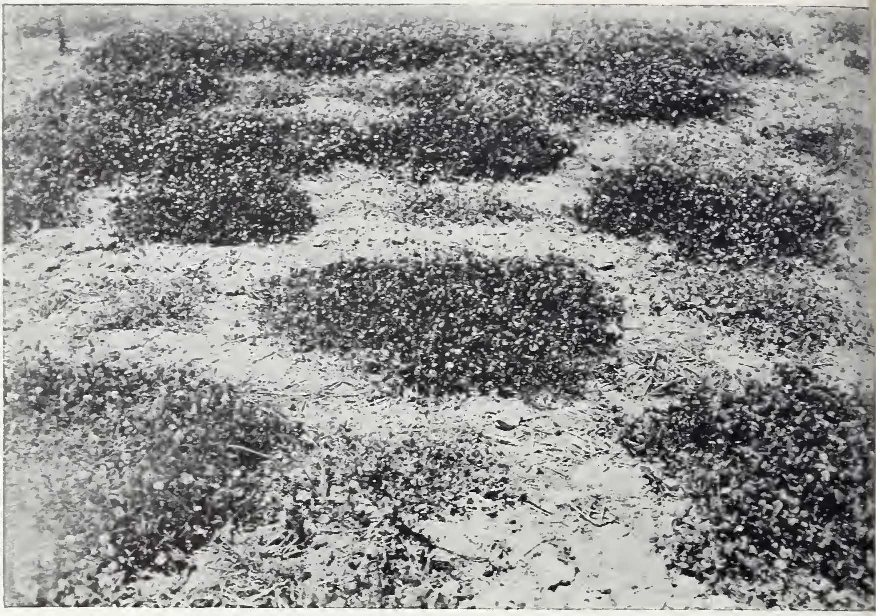

FIGURE 11.—Two-year-old Ladino clover plants vary in their resistance to mottling. The small plants are susceptible to the disease and do not grow as vigorously as the neighboring healthy plants.

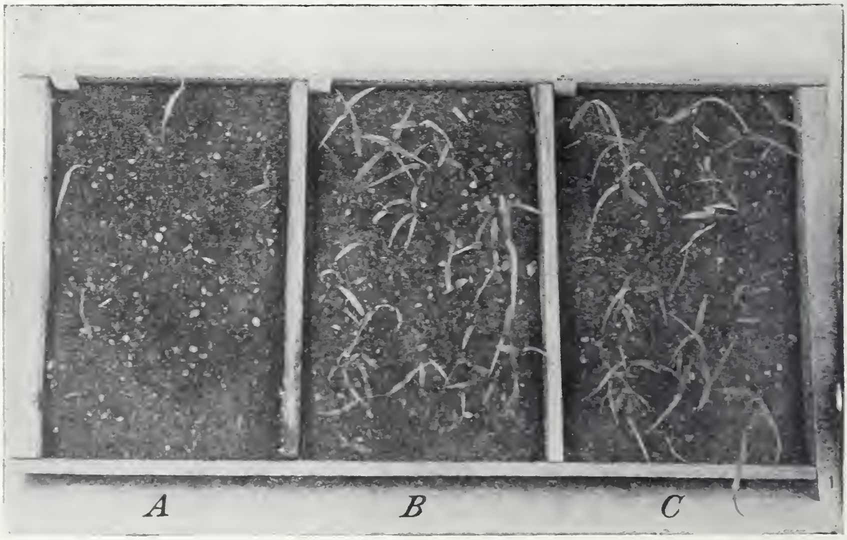

FIGURE 12.—Sixteen-day-old plants of Sudan grass in flats. The seeds planted in *A* were untreated, those in *B* were treated with Spergon, and in *C* with Arasan.

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